

Performance of 1 kHz KrF excimer laser for DUV lithography

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ABSTRACT

In response to the requirement for higher wafer throughput and increased dosage accuracy in DUV lithography steppers and scanners, Cymer has developed a 1kHz KrF laser optimized for this application. We shall describe its performance and design features.

Keywords: KrF lasers, Deep Ultraviolet photolithography, SCR switched pulsed power

2. INTRODUCTION

Chip makers are gearing up for 686-class micro-processors and 64Mbit production. These require producing 0.35 μ m design rules. They are also focusing on 256Mbit DRAMs that require 0.25 to 0.35 μ m design rules (Figure 2.1). Therefore, the shift from mercury lamp based I-line to 248nm DUV steppers has begun in earnest. Current KrF laser models from several suppliers satisfy the optical/uptime requirements necessary for pilot production, and are beginning to compete well with I-line steppers.

3. LASER PARAMETERS AFFECTING STEPPER/SCANNER OPERATION

The parameters that affect the operation of a stepper or scanner are now well understood (Table 3.1)¹. A multifaceted relationship exists between the laser and stepper/scanner. Such is not the case with the mercury arc lamp and the stepper. As the move towards higher Mbit DRAMs and faster processors occur, the requirements for narrower linewidth KrF lasers increases, as shown in the table. Higher throughput and dose control accuracy require higher repetition rates and precise control of laser's energy reproducibility. Therefore, several laser sub-systems were re-examined during development of 1 kHz laser (Figure 3.1). Finally, the DUV lithography process has moved from the R&D laboratory to the pilot production line. Therefore, the lasers have to meet a host of international safety standards.

3.1 Chamber

By far, the most critical module in the laser is the chamber². The all-metal and ceramic chamber was re-designed to improve flow uniformity between electrodes and minimize blower power requirements (~30% of total input power). Flow guides introduced in the chamber eliminated flow non-uniformities, resulting in linear laser power with repetition rate. The linearity is required to achieve long gas life (100 M pulses between refills) and minimize peak-to-peak energy variations.

3.2 Pulsed Power

At 1kHz, the traditional approach of using a thyratron switched pulsed power system is inadequate (Table 3.2). An all solid-state pulsed power system³ was optimized for 1kHz operation. The energy-recovery feature in the pulsed power unit reduces energy into the discharge in the post-pulse period (Figure 3.2), resulting in increased chamber life and gas life.

3.3 Line Narrowing

The high NA steppers require narrow linewidths (<0.8pm, FWHM). The line narrowing technique utilizes an echelle grating in combination with beam expansion prisms. For short duration KrF laser, the final linewidth ($\Delta\lambda_f$) is related to the single pass linewidth ($\Delta\lambda_1$) via the equation:

$$\Delta\lambda_f = \frac{\Delta\lambda_1}{\sqrt{n}}$$

where n is the number of round trips. Since the number of round trips is small, 3 or 4, the single pass linewidth is designed to be a factor of two higher than the desired linewidth of 0.8 pm (Figure 3.3). This means that the magnification of the prisms is very high. However, this technique is susceptible to

deviations in material flatness or homogeneity which increases linewidth. The problem of small wavefront curvatures is corrected by introducing a small curvature ($R \sim 0.5$ to 10 km) in the grating.

3.4 Energy Stability in Stepper mode operation

The step-and-repeat lithography process has many steps, such as wafer loading, pre-alignment, exposure and stepping of die. Once in the ready state, the laser may be operated in short bursts (30 to 60 pulses), separated by rest periods (100 to 1000 ms). After exposure of one wafer, the wafer exchange step takes several tens of seconds, during which the laser remains idle. The burst mode makes laser operation unstable in energy & spectral performance at the beginning of few pulses of each burst. After few pulses, the energy is more well-behaved implying that the energy can be stabilized. Fortuitously, it has been observed that the energy behavior during the start of the burst is fairly repeatable. The laser's control system software is "trained" to compensate for this behavior. However, further investigation on the characteristics of the second laser pulse as a function of delay wrt the first pulse revealed interesting facts about the role of gas flow in controlling energy stability (Figure 3.4). The re-entrant gas during the second discharge retains some memory of the first discharge. The effects of re-entrant gas can be minimized by proper premixing of the gas prior to its re-entry into the electrode region. By a combination of software and gas flow engineering, the energy stability of the laser in the stepper mode can be improved significantly.

3.5 Energy Stability in Scanner mode operation

For scanner operation, the Energy Stability of laser impacts dose (which is the integrated energy over a burst) accuracy. The lasers are designed to operate in the range where dE/dV is the lowest (Figure 3.5), so that small fluctuations in the voltage do not create large fluctuation in energy. Therefore, lasers are designed such that they operate at or near 600V. With big improvements in manufacturing technology, today, Cymer can control the variability of the starting operating voltage to within 3%, i.e. all lasers operate at $600 \pm 3\%$. For scanners, the total dose is more appropriate than energy stability. The control software, therefore, attempts to minimize the deviation in the integrated dose during a burst by using a non-linear algorithm. Although the energy stability can be as much as 10%, the integrated energy can be controlled to within 1% for bursts as small as 50 pulses.

4.0 RELIABILITY AND COST-OF-OPERATION

Beam and system parameters have to be met throughout the life of the laser. Therefore, the laser is subjected to rigorous life/reliability tests. However, the present understanding of reliability goes beyond testing a laser for several billion pulses and documenting the failure mechanisms. Instead, Failure Reporting, Analysis and Corrective Action System (FRACAS) gathers reliability data. FRACAS is a SEMATECH created database program used to collect, record and analyze failures. Database logs and classifies all failures. It then tracks and monitors solutions to ensure closure of all problems. All laser failures starting with manufacturing build through system end of life are logged in FRACAS. Pareto analysis and other statistical reports generated by FRACAS help Cymer understand the reliability of ELS-5000. Therefore, reliability data is gathered from multiple sources, under multiple conditions to help Cymer track failures due to design, infant mortality, or lifetime.

5.0 CONCLUSION

After ten years of development, the stepper/scanner manufacturers, working in conjunction with excimer laser manufacturers have taken DUV lithography technology from R&D to pilot production. Simultaneously, the laser manufacturers have refined manufacturing techniques, introduced process controls and implemented reliability programs to effectively compete with I-line based steppers/scanners.

6.0 REFERENCES

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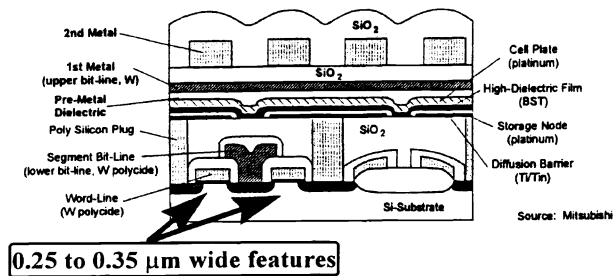


Figure 2.1 256 Mbit DRAM Structure

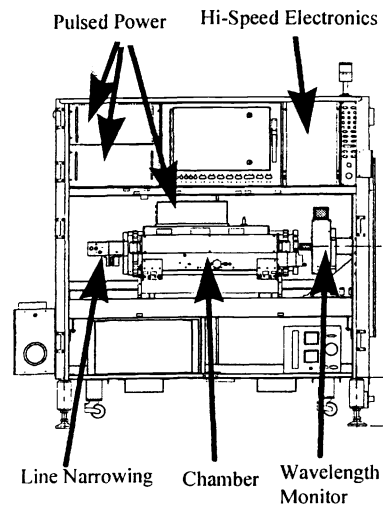


Figure 3.1 ELS-5000 and sub-systems

Table 3.1 Parameters that affect stepper/scanner operation

Spectral Bandwidth and Spectral Energy Distribution	⇒ (affects)	Resolution, Depth of Focus
Relative Wavelength Stability	⇒	Focal Plan Stability (long term) Resolution, D.O.F., (Short Term)
Absolute Wavelength Stability	⇒	Magnification, Distortion
Output Power	⇒	Throughput
Repetition Rate	⇒	Energy Dose Accuracy, Speckle Reduction
Pulse-to-Pulse Energy Stability	⇒	Energy Dose Accuracy
Beam Profile, Beam Pointing & Beam Divergence Stability	⇒	Exposure Uniformity, Illuminator Efficiency
Polarization Stability	⇒	Illuminator Efficiency
Spatial Coherence	⇒	Speckle, Exposure

Table 3.2 Differences in Thyatron and SCR-switched Pulsed Power

Thyatron Switched	Solid State Switched
<p>Advantages</p> <p>(1) Simple, with few components.</p> <p>Disadvantages</p> <p>(1) Thyatron dissipates significant energy due to its losses. Increased losses cause thyatron heating and unpredictable prefires.</p> <p>(2) Energy after Laser Pulse is dissipated in thyatron and laser electrodes, causing thyatron and electrode erosion.</p> <p>(3) 10 min. warm-up.</p>	<p>Disadvantages</p> <p>(1) Complex, many components</p> <p>Advantages</p> <p>(1) No unpredictable pre-fires. Very important for scanners.</p> <p>(2) Energy after Laser Pulse is recovered and used for subsequent pulse. This energy recovery increases system efficiency and laser chamber life. Scaling in repetition rate to 1 kHz is easier.</p> <p>(3) "Instant -on", no warm-up.</p> <p>(4) 15 times longer life than thyatron</p>

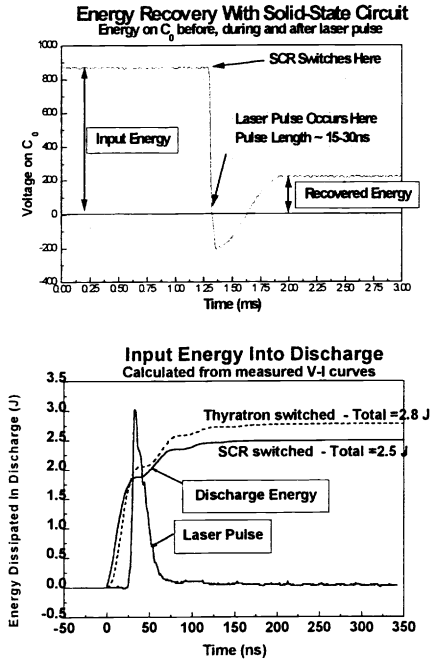


Figure 3.2 Energy recovery with SCR switched solid-state pulsed power system

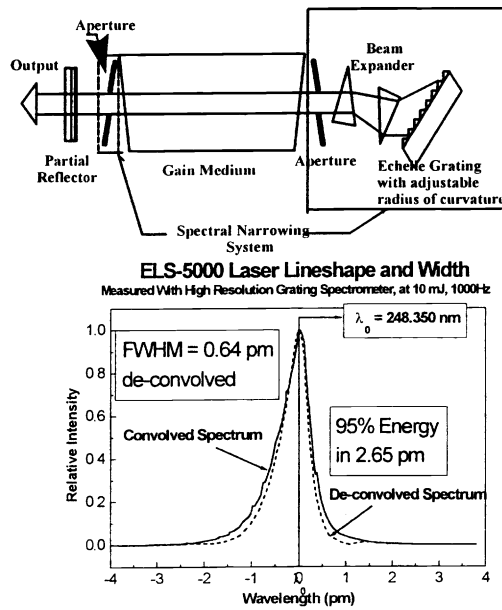
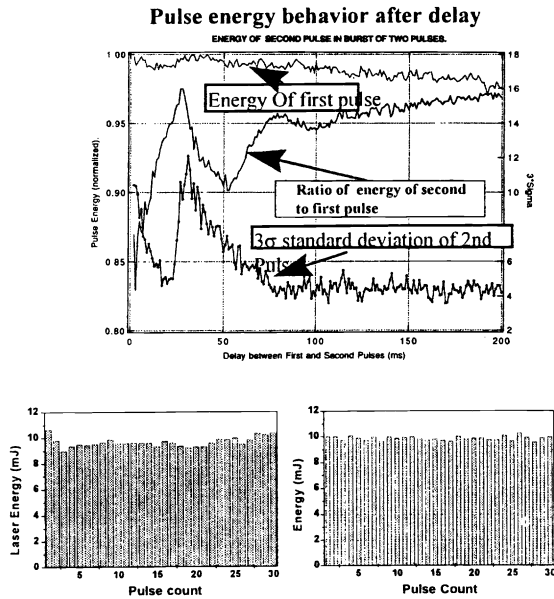


Figure 3.3 Line Narrowing system and spectral profile



Without software, $3\sigma = 10\%$ With software, $3\sigma = 6\%$

Figure 3.4 Energy Stability during stepper operation

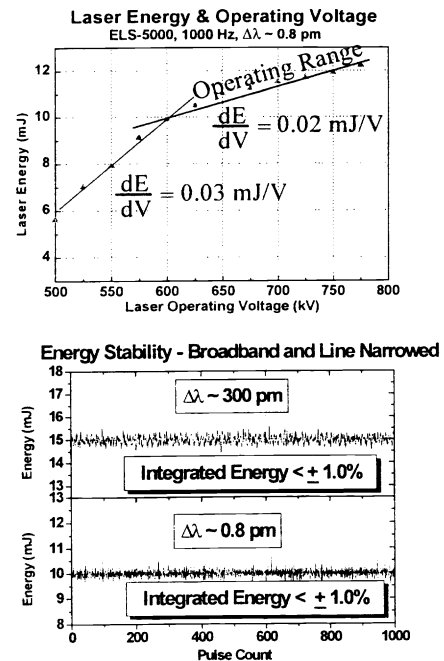


Figure 3.5 Energy Stability during scanner operation